NATO PARLIAMENTARY ASSEMBLY

ECONOMIC AND SECURITY COMMITTEE (ESC)

THE FUTURE OF THE SPACE INDUSTRY

General Report

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I. INTRODUCTION

1. Sixty years ago, the Soviet Union successfully launched the first artificial satellite; Sputnik I. This event inaugurated what came to be known as the Space Race, a period of intense direct competition for supremacy in space mainly between the United States and the Soviet Union. It was hardly surprising that other actors were initially excluded from this competition given the scale and costs of the effort the two superpowers were willing to undertake. The US National Aeronautics and Space Administration's (NASA) Apollo programme, for example, employed more than 400,000 people and cost USD 110 billion when adjusted for inflation (Baiocchi and Wel, 2015). Additionally, early space programmes posed inordinate risks and led to various training and spaceflight-related deaths and injuries. These costs far exceeded what most countries were willing to bear, and no individual or private company would ever even have considered embarking upon such an undertaking without state support.

2. Despite these costs, space programs accorded significant strategic and economic benefits. While there is no definitive study on the full technological impact of space programmes, commercial spin-offs from national space programmes have clearly had a major impact on the economy of the United States and is inextricably linked to the digital revolution. The US space programme helped nurture a network of firms capable of commercially exploiting emerging technologies. Thus, the need for advanced computing and smaller electronics for space flight contributed to significant advances in a range of fields from computers to advanced materials. Satellites, which were essentially built by governments for military surveillance and reconnaissance, ultimately enabled global telecommunications and GPS technologies. One study on the macroeconomic effects of the US space programme suggests that each dollar spent on research and development yielded an average of slightly over seven dollars in commercial returns over an 18-year period (Schnee, 2000).

3. The close links between space projects and commercial endeavours are once again a headline generating phenomenon. All the leading space powers are advancing important exploration programmes: China's Moon programme and various Mars programmes (driven by private players such as SpaceX NASA and the European Space Agency (ESA). Space remains a critical frontier for strategic and economic competition among states, and this effort continues to produce significant technological advances. Moreover, the list of states with national space programs has increased markedly. Europe has pooled its efforts through the European Space Agency, and, since the Lisbon Treaty, it has collectively derived a benefit of scale through EU programmes such as Galileo and Copernicus. China, India and Japan are now prominent players, and a number of other countries have also entered the field. International cooperative programs have resulted in new links being created, often in the form of common projects.

4. Space-related technologies have helped drive this growth and played an essential role in knitting together an interconnected USD 78 trillion global economy (NATO PA, 2017). At the same time, they have enabled nuclear deterrent systems, facilitated ground, air and sea-based military operations, and triggered major advances in meteorology, Earth observation, mapping, the internet and communications. Although the original paradigm for space exploration was one of a Cold War race for predominance, space has also become an arena of significant international cooperation. The International Space Station (ISS) is a perfect expression of interstate collaboration in space, and there are myriad examples of shared missions, international procurement and joint scientific projects.

5. At the same time, space remains an important arena for interstate competition, perhaps best encapsulated in the proliferation of intercontinental ballistic missiles but evident also in areas such as missile defence, military communications, command and control, surveillance and intelligence gathering. The United States government still spends over USD 40 billion annually on space, with the funding largely split between the Pentagon and NASA. European Space Agency member-states spend over USD 6 billion each year while Russia spends an estimated USD 1.6 billion on its space endeavours (European Space Agency, 2016). Precise figures for China remain elusive.

6. A revolution in space funding, exploration and commercialisation is also underway. Spurred by major technological advances and the promise of triggering technological and commercial breakthroughs, new actors, including developing countries, private firms and even individuals are now playing in an arena once dominated almost exclusively by powerful countries. These actors are altering the dynamics of the space industry and raising important commercial and strategic questions for policymakers in all NATO member states. This general report will explore the paradigmatic shift that is now broadly labelled "new space" and identify the key opportunities and challenges that NATO member states confront as this critical dimension of human activity undergoes a revolution in technology, opportunity, expectations and leadership.

II. CHANGING DYNAMICS OF THE SPACE INDUSTRY

7. One of the features of new space is that private firms are no longer simply operating as contractors to nation states but are themselves becoming key protagonists in space. To take one notable example, in 2018, SpaceX launched 15 rockets, which among other things sent a Luxembourg-made satellite to be used by NATO into orbit. It also sent a Tesla automobile into space as a marketing stunt and a way to announce that the company was prepared to reinvent the way companies conceive of space (SpaceX, 2018). In in 2017 that company launched 18 rockets and recovered 14 reusable boosters (The Economist, 2018). Blue Origin plans to launch the first tourists into space by April 2019 (Wattles, 2017). Commercial actors are also roiling European markets and compelling traditional actors to up their game. Europe itself has become an ever more important protagonist in space and European firms now rival their American competitors across an array of technologies and are thus helping to advance European ambitions. At the same time, developing countries are making significant advances in their own their space programmes. China may now be spending more on space than the Russian Federation (Clark, 2016). Indeed, more than 60 states currently own and operate satellites, and the space market is growing ever more globalised and diverse (OECD, 2016).

8. Traditionally, investors have considered the commercial opportunities of space to be "high risk, high cost, and [characterised by] long payment periods" (Wakimoto, 2018). In 2011, NASA estimated that the average cost of a manned space shuttle mission was USD 450 million, with unmanned rockets costing roughly USD 420 million each (Bray, 2017). Insurance costs, meanwhile, can amount to USD 800 million (Basak, 2016). This figure is nonetheless a high estimate of the annual insurance market, with insurance representing on average about 10% of the cost of a launch. Even discounting the potentially catastrophic financial and reputational cost of a launch failure, opportunities for significant profit in the industry have long seemed limited. Until 1982, the US government was responsible for launching all civil and commercial payloads within its borders. Launch vehicles themselves were only produced under contract with the US government, and the bidding process for these contracts tended to be non-competitive due to the government's reliance on a limited number of aerospace giants and its need for supply security over cost competitiveness (Berger, 2017).

9. Several important changes, however, have dramatically reduced barriers to entry and increased private interest in space. First, gradual improvements in managerial practices and the falling cost and size of technology are slashing launch and payload costs. SpaceX has expressly designed its Falcon rockets, for example, to maximise standardisation, which, in turn, has reduced the number of processes and the tooling required prior to any given launch while diminishing unit costs of critical parts. Advances in rocket engine design, meanwhile, have lowered combustion instability and driven down the material costs (Chaikin, 2012). The digital revolution and minutarisation have increased the power of critical satellite technology while reducing its size and weight—key drivers of launch costs.

10. Driven by these changes, the space sector has begun to have a more profound impact on the broader economy. Ever-smaller telecommunications satellites are now playing a pivotal role in corporate strategy by offering space-based solutions to inherently Earth-bound problems (OECD,

2016). As savings from these advances mount, companies are encouraged to build upon existing space-based systems and to develop new capabilities serving an ever expanding array of commercial markets.

11. Reusable rockets are among the most promising of these advances provided the restoration costs, which are currently very high, are under control. This technology substantially reduces costs by allowing officials to launch the same rocket multiple times. In 2010, SpaceX launched a payload into orbit with the rockets returning to Earth for eventual reuse. This made it the first non-government entity ever to achieve this feat. In 2015, it recovered the first stage of one of its rockets (Kluger, 2018). In 2017, it launched one of the most powerful rockets in human history and successfully landed its two outer stages, which can now be redeployed in future missions (Hern, 2018). In 2015, another private company, Blue Origin, designed and launched a reusable suborbital rocket, which will help that company substantially reduce its production costs (Kim and Orwig, 2017).

12. Traditionally government support has been a critical driver of technological change linked to the space industry. Private corporations in the United States, for example, were long granted access to their country's space agency's technical archive. They also benefited from the secondment of NASA experts. These favourable conditions helped these firms to make technological leaps that took decades to refine and billions in public funds to finance (Chaikin, 2012). Cooperation between government scientists and private industry triggered compelling advances in an array of critical components, such as heat shield materials, that ultimately also had important commercial applications (Werner, 2015). Governments have also played a compelling financial role and sustaining the space sector through a system of research grants, contracts, and other agreements with the private sector. Even after a technology's usefulness is demonstrated, it can still require significant direct or indirect public support before it becomes a marketable component or platform. Investment costs can be daunting, and the risks often remain too high for companies alone to shoulder (OECD, 2016). The United Launch Alliance, a joint programme between Boeing and Lockheed Martin, for example, receives roughly USD 800 million a year from the US military through a launch capability contract (Gruss, 2016).

13. In the United States, however, there is a strong risk-taking ethos linked to its entrepreneurial culture, and other financial options have emerged. The role of so called "angel-financiers" played a critical role in the rise of the digital economy. These risk-taking investment companies poured billions of dollars into start-ups with good ideas and talented engineers but little capital to help them bring these ideas to fruition. The success of this model is well documented and some of it has spilled over into the space market. That should hardly be surprising, particularly as the digital revolution itself is a central feature of the new space paradigm. In any case, those pushing the technological and commercial frontiers of space in the United States have financial options that are less available in Europe and Japan, for example. It is accordingly correct to speak of different national models at play in this rapidly changing sector.

14. Managerial revolutions are another element of the story. Driven by competition, leading companies have reduced production costs and sped up production lines by tightening up supply chains, tapping into robotics and digital printing technologies, and even producing key components in-house. The ArianeGroup in Europe, for example, is using digital printers to manufacture its own critical titanium components and has made enormous savings doing so (NATO PA Visit to Paris and Toulouse, October 2018). SpaceX manufactures and assembles more than 70% of its launch vehicles to reduce its dependence on any single supplier (SpaceX, 2013). Off-the-shelf components can play a critical role in driving down costs. SpaceX claims to save between USD 45,000 and USD 95,000 for a single radio compared to the price of radios aerospace companies typically purchase (Koebler, 2015). Blue Origin recently unveiled its own rocket factory that will be responsible for designing and rebuilding reusable rockets (Kim and Orwig, 2015). Virgin Galactic has assembled a vertically-integrated team capable of producing and testing many rocket components in-house (Foust, 2015). For new entrants to the market, expertise is increasingly consolidated within single firms instead of across a multiplicity of vendors and contractors. The process of designing, testing,

and improving products in all of these companies has been streamlined in new and innovative ways. Creative management and new design approaches have thus been central to slashing costs in this burgeoning industry.

15. Increased competition has made such cost-cutting essential. For a long time, government largesse helped insulate the commercial space industry from traditional market pressures. Reflecting its space programme's national security and prestige-based origins, the US government passed laws that imposed restrictions on the ability of foreign companies to work within its borders. This undermined the kind of dynamism that trade competition generally encourages and some of these practices, many of which are rooted in security concerns, persist (Zelnio, 2006). The International Traffic in Arms Regulation (ITAR), for example, sets restrictive rules on the trade of US technologies, and this actually helped galvanise European manufacturers to develop their own technologies outside of US export controls (Hauser and Walter-Range, 2008). ITAR's broad mandate, extraterritorial reach, and slow and unpredictable process, almost paradoxically fed the proliferation of non-US space firms developing their own technologies and pushing the frontiers of space in new directions.

16. In the United States, major companies like Lockheed Martin and Boeing overcame these barriers thanks to exclusive contracts with the US government. But this left smaller competitors effectively barred from the market. The government had few options but to sign exclusive agreements with large space companies. In effect, government policy helped create monopolies or at least oligopolies and this failed to provide sufficient incentives to innovate or drive down costs.

17. In 2014, however, the US Department of State reclassified most commercial, civil and scientific satellites and accompanying equipment under the Department of Commerce's "Commerce Control List" (CCL) making it significantly easier for private companies in the US space industry to sell in the international market. Whilst ITAR still restricts many aspects of the US space industry, this revision constituted an important step towards loosening restrictions that were impeding the market.

18. Lawsuits, policy changes, and a growing awareness of the economic consequences of ITAR rules sparked a degree of rethinking in the United States and elsewhere. New policies have encouraged competition and helped open the commercial market to other actors. This competition has, in turn, created incentives for the industry to build ever cheaper and more capable products. In 2006, NASA stopped using government-operated rockets to resupply the International Space Station and has since relied on private industry (Grush, 2017). A subsequent analysis of this change found that NASA spends roughly USD 89,000 per kilogram of cargo. The same service by a traditional aerospace giant would have cost USD 135,000 per kilogram while a government-run service would have cost USD 272,000 per kilogram. The same analysis also estimated the cost of a start-up firm running a crew rotation for the International Space Station as compared to a similar operation conducted by an aerospace giant. The former would cost USD 405 million while the latter would be priced USD 654 million (Zapata, 2017). According to analysts, SpaceX charges USD 4,653 per kilogram to launch a telecommunications satellite into orbit while traditional aerospace companies charge between USD 14,000 and 39,000 per kilogram (Routh, 2017). This represents a profoundly disruptive change to the industry with long-term commercial, scientific and even military-security implications. The price fall is a function of regulatory change, managerial innovation, competition and critical technical innovation.

19. These advances have also sparked intense interest among well-financed space enthusiasts and entrepreneurs. Motivated by an abiding personal interest in space and driven by a belief that he could dramatically drive down costs, Elon Musk, the US entrepreneur who earned millions after selling his firm Paypal, founded SpaceX with a USD 100 million investment primarily composed of his own money (Tilley, 2016). Jeff Bezos, the founder of Amazon, is selling USD 1 billion of stock a year to finance his aerospace company, Blue Origin (St. Fleur, 2017). These entrepreneurs have a personal interest in space and a belief that they can push out the space frontier while identifying

projects that can generate long-term profits. Their personal wealth has afforded them the opportunity to stretch out investment horizons in this changing but still high-cost and risky business.

III. STATE OF THE CURRENT COMMERCIAL SPACE MARKET

20. Although there has been a tendency to focus on the large players in the US space industry, Europe has emerged as a major player in these markets. The French company Arianespace, for example has been a key innovator in commercial launch services. European satellite manufacturers and operators, such as Airbus DS, Thales Alenia Space, OHB, Eutelsat and SES, rank among the world leaders. The US government, however, spends significantly more on space-related activities than any other country. In 2014, the institutional space budgets of the United States exceeded USD 4 billion, significantly more than any other countries (OECD, 2014). Its commercial space sector has been bolstered by innovation, risk taking and a financial structure that encourages risk taking and seeks to reap large rewards as pay off.

21. The commercial space industry, however, is growing increasingly globalised, and there are challenges to traditional US dominance. European companies, for example, now control about 40% of the world market for satellite manufacturing, launching, and operations (European Commission, 2009). Although its position has recently declined due to launch failures and the rise of less expensive alternatives, the Russian Roscosmos provided NASA with rocket components as recently as 2014 (Wright, 2014). Virgin Galactic, a company founded by a British investor, Richard Branson, has invested substantial resources into commercial spacecraft and suborbital spaceflights.

22. Though rapidly evolving, the current space industry can be divided into three core sectors: Satellites; Launch Services; and Ground Equipment. The following section explores the current environment shaping these sectors and points to the direction in which they are now moving.

A. SATELLITES

23. Satellites make up the most developed sector of the space industry due to their place in the architecture of the global economy. From 2012 to 2017, the number of satellites in space increased from 994 to 1,459. This number is expected to rise to 7,000 within several years (NATO PA visit to Paris and Toulouse, October 2018. Meanwhile, revenue across the sector increased from USD 113.5 billion to 127.7 billion (Bryce Space and Technology, 2017). Though satellites serve myriad functions, the sector itself can be divided into two parts: manufacturing and services. Designing, deploying and maintaining these systems is a highly complex and expensive undertaking, but it can generate enormous paybacks. The generated know-how involved spillovers into other commercial sectors beyond those directly involved with satellite production. The city of Toulouse, France, provides a case in point. Its booming economy is driven not only by its large satellite industry, but also by the spin-offs this sector generates, which have helped launched an array of other industries in everything from digital services to material engineering.

24. While governments and companies across the globe increasingly rely on satellites, the manufacture of these systems remains relatively centralised in a handful of companies that possess the skilled workforce, the scale, engineering capacity, and financial resources needed to produce reliable complex systems. These organisations include the European Thales Alenia Space, Airbus DS and OHB as well as various US companies, such as Maxar Technology (formerly SSL), Boeing, Lockheed Martin, and Orbital ATK. As the above list suggests, the United States is the largest manufacturer of these spacecraft, with Europe and Russia rounding out the list (Canis, 2016). In 2016, government agencies purchased 382 satellites, almost three quarters of all devices launched. Satellite manufacturing has thus been largely driven by government demand. But this demand can fluctuate significantly over time. In 2016, for example, yearly commercial revenue shrank 13.1% partly because the government and private-sector customers had reached the end of their satellite replacement cycles, the period in which an active satellite must be replaced (Bryce Space and

Technology, 2017). Some analysts suggest that the market suffers from significant overcapacity and has been hindered by delayed investment decisions in the conventional geostationary transfer orbit (GTO) satellite market. The expectation is that commercial demand will help reduce reliance on state customers and help fill orders.

25. Satellites are very expensive, but costs are declining with the advent of small satellites, also known as "minisats", which weigh less than 500 kilograms and "nanosats," that can weigh as little as 3.5 kilograms. These small satellites are able to carry out certain tasks that were once only conducted by far larger vessels. Rapid advances in consumer electronics have transformed satellite technology and driven down costs and size. As price decreases and performance increases, the cost of manufacturing complex satellites accordingly falls. One small satellite producer, the US-based Orbital Sciences, claimed several years ago that its production and launch costs had fallen to between USD 150,000 and 1 million compared to the typical cost of USD 200 million to USD 1 billion for larger alternatives with similar functionality (The Economist, 2014). British manufacturer SSTL, the world leader in small satellites, offers entry-level solutions for less than USD 1 million. Larger satellites feature functionalities superior to those of small satellites. The Airbus-OneWeb satellite programme aims to launch 900 microsatellites - that weigh between 10 and 20 kilograms - that will collectively provide affordable internet access to the entire world. The first of these micro satellites are being deployed in 2018. This is a highly ambitious trans-Atlantic project that has also demanded very rapid satellite production lines relying on robotics. The project has produced innovation on that front as well. SpaceX also plans to launch thousands of small satellites to enable global internet (Wattles, 2018). These kinds of innovations are believed to have generated an 11% increase in revenue for the Earth imagery industry in 2016 (Klotz, 2017). Payloads averaging 13.1 kilograms are thought to have made up a quarter of all launches in 2016.

26. According to the OECD, the top 25 actors in fixed satellite services, the architecture of which relies on ground terminals, generated USD 12 billion in revenue in 2013. Though the top five players in this particular market represented 70% of that revenue, this share has dropped due to increasing competition from emerging players (OECD, 2014). Satellite broadcasting, meanwhile, is estimated to have a market of USD 92 billion. As of 2017, satellite television made up almost a third of space-related commercial activity (Canis, 2016).

27. Satellite services extend well beyond telecommunications. Earth observation start-ups raised USD 96 billion in 2017. The industry is moving rapidly from the business of collecting imagery from all over the globe to transforming data into actionable intelligence. Data analytics is expected to generate significant earnings for this sector over the coming years (Komissarov, 2018). This information is used to track trends in agriculture, disaster mitigation, mass migration, shipping, as well as to track piracy and other criminal activities including environmental crime. Atmospheric monitoring-satellites track weather patterns and help provide daily weather forecasts as well as predict droughts and floods. Transportation-related satellites provide geolocation services to consumers, delivery trucks, such as FedEx, and ride-sharing services, such as Uber (Canis, 2016). These same kinds of services obviously have important military applications and national security forces and intelligence agencies will remain important clients for the business. It is worth noting that originally, the GPS constellation was a military system and the Galileo programme will have a classified military dimension for EU members only.

B. LAUNCH SERVICES

28. The launch sector is perhaps less a driver of the space industry than it is an enabler for other activities. As much as the industry demands sophisticated electronics and well-engineered devices, it also needs to get this equipment into orbit. This poses a range of financial and technological challenges. In 2017, the United States, China, Russia, the European Union, India, Japan, Israel, Brazil and North Korea conducted 90 launches. Of these, 64 were commercially procured, 13 were not commercially procured, and 13 involved space vehicles (Bryce Space and Technology, 2018).

Between 2004 and 2014, private companies sent an estimated 817 satellites into orbit, with 41% of these relating to telecommunications and 21% relating to Earth observation (Euroconsult, 2015).

29. The commercial launch sector is estimated to be worth USD 5.4 billion and, in 2015, clients booked USD 2.6 billion in launch services (Canis, 2016). While the number of launches ebbs and flows over time, most experts expect an upward trend in the sector's activities and profitability. Declining barriers to entry will likely spur additional growth and there seems to be an ever-larger space for commercial as opposed to government programs. In 2015, US companies conducted eight commercial launches (Dillingham, 2016). Between 2013 and 2018, SpaceX's share of the global commercial market grew from 5% to over 60%, while Roscosmos, Russia's state-run company, saw its share sharply decline from almost 50% to 5% (Hughes, 2017). Government-controlled facilities, such as the Kennedy Space Center in the United States and the Guiana Space Centre (CSG) in Kourou, have traditionally served as launch sites for commercial entities under very different economic conditions. SpaceX uses NASA's facilities almost for free, which is not the case for Ariane at the CSG, which charges EUR 20 million per launch. In the United States alone, there are 19 active and licensed launch sites, ten of which are operated by US states in partnership with private industry. There are an additional three non-licensed sites, which can exist because companies own and operate them and exclusively use their own vehicles (Federal Aviation Administration, 2017).

30. As discussed above, new market entrants and improved rocket technology drive many of these transformations. Reusable rockets, a recent innovation successfully tested by SpaceX in 2018, represent an especially promising advance that will further reduce costs and launch turnaround time. Nevertheless, this production choice which reduces the number of rockets produced, entails an increase in unit price. How quickly this technology will be integrated into the sector's regular services is not yet apparent.

31. One possible limiting factor on the launch industry is the extent to which the sector is "captured" by established companies. As the US Federal Aviation Administration noted in its 2018 assessment of the sector, most satellite operators have exclusive agreements with launch providers and are prohibited from "shopping their services around" (Federal Aviation Administration, 2018). Such exclusivity could limit potential savings insofar as it restricts competition, which invariably leads to higher than necessary prices.

C. GROUND EQUIPMENT

32. The final notable component of the space industry is ground equipment, which refers to the Earth-based infrastructure that directs the information transmitted from satellites to appropriate transmitters and receivers. This infrastructure includes antennas that allow for transmission and reception of different communications signals, such as satellite radio and television. It also includes user terminals, such as rooftop dishes for satellite televisions, large corporate dish antennae, and data accounting and distribution systems, which identify and respond to errors in transmission. Such systems tend to be highly automated and are only occasionally monitored by individuals (Canis, 2016).

33. With revenue amounting to USD 119.8 billion, of the total USD 248 billion revenue of the industry, ground services constitute a significant 34% of the space industry. Its largest segment, consumer equipment, including global navigation systems (GNSS), contributed USD 108 billion of those USD 119.8 billion. (The Space Industry Association, 2018) GNSS systems include small consumer products, such as standalone navigation devices and location-detecting chips in mobile phones, as well as larger, more complicated systems, including traffic control systems, aircraft avionics, and maritime trade networks. An additional USD 18.5 billion is spent on non-GNSS consumer equipment, including satellite television, radio, and broadband terminals, while a final USD 10 billion is spent on network equipment such as satellite news-gathering equipment (Bryce Space and Technology, 2017). Growth in this sector can be attributed to the growing need for GNSS

chips in smartphones and other consumer products. As a result, between 2012 and 2016 alone, GNSS equipment grew from a USD 52.7 billion industry to one that generates USD 84.6 billion (Al-Ekabi, 2017).

D. POTENTIAL FUTURE MARKETS

34. The media spends an inordinate amount of time and print exploring the ambitious plans of emerging space companies and the entrepreneurs that lead them. Elon Musk, the CEO of SpaceX, and Jeff Bezos the owner of Blue Origin, have attracted a great deal of attention, and they have leveraged their personal wealth to build these ambitious firms. Because these firms are somewhat insulated from the immediate shareholder demands, they are positioned to focus on long term project including Moon and Mars missions, asteroid mining and space tourism as well as more immediate activities including rocket engine and launcher production.

35. Tourism in space is not a new concept and was evoked even prior to the advent of the space age. However, in recent years, the notion has become considerably less abstract. Since 2001, brief orbital spaceflight has been available through expensive private ventures costing upwards of USD 20 million (Carrington, 2013). In 2017, SpaceX announced that it had booked two private space tourists for a trip around the moon in 2018 (SpaceX, 2017), but in February 2018, Elon Musk decided to delay the trip until the new Big Falcon Rocket is available (Clark, 2018). Other companies such as Blue Origin and Virgin Galactic have also devoted significant efforts to space tourism, with Jeff Bezos' Blue Origin planning to open the service in 2019 (Clark, February 2018). The Russian Space agency has sent 7 paying clients into space.

36. The sustainability of these efforts, however, remains to be seen given unclear market demand, the possibility of catastrophic failure and potential liability, and the enormous investments that civilian space travel would require. The sector will at best remain a niche market for the extraordinarily wealthy. Short spaceflights, epitomised by SpaceX's effort, appear more likely and feasible than any long-term stay in space given the lack of necessary infrastructure and the high costs of such travel. The US Government Accountability Office does not believe any commercial company will be accredited to fly government astronauts until 2019, suggesting that a sustainable civilian space travel sector is not likely to emerge over the medium term (Government Accountability Office, 2017).

37. A second often discussed commercial enterprise relates to the mining and recovery of natural resources outside of the Earth's orbit. Throughout the universe, there are significant deposits of natural resources that theoretically could be recovered. Asteroids, for example, can contain nickel, platinum, iron, and cobalt. NASA estimates that the asteroid belt between Mars and Jupiter, where over 1 million asteroids exist, has an estimated value of USD 700 quintillion (Desjardins, 2016). Several landings on large asteroids have already been undertaken to demonstrate the technical feasibility of beginning this industry, but the current cost structure would not seem to justify major efforts in this arena, at least at the moment. According to the Keck Institute for Space Studies at the California Institute of Technology, capturing a 500,000kg asteroid would cost around USD 2.6 billion and require significant advances in propulsion systems and ground-based observation, as well as a human presence in lunar orbit (Keck Institute for Space Studies, 2012). Given the costs, resource recovery likely remains decades away. Any natural resource recovery would also likely require a reworking of international treaties, such as the Outer Space Treaty, that prohibit states from claiming celestial bodies.

IV. NATO AND THE COMMERCIAL SPACE INDUSTRY

38. As the Alliance recognised in its 2010 Strategic Concept, maintaining unimpeded access to space is a major priority for the NATO and its members. Moreover, all members of the Alliance depend upon the vast network of shared space assets for deterrence, strategic communications, and navigation. As the NATO Parliamentary Assembly's Sub-Committee on Future Security and

Defence Capabilities emphasised in its 2017 report, *The Space Domain and Allied Defence* [162 DSCFC 17 E rev.1], "NATO needs a whole-of-alliance approach to protect its interests in space to enhance resilience and deter any threat to its space-based capabilities" (NATO PA, 2017).

39. NATO itself is not currently focused on the space domain even if it remains important to areas like intelligence and surveillance and in missile defence. There are currently just six postings in NATO designated as space-operations positions in six different departments. Following the acknowledgement of the support that space assets have provided to NATO missions, especially the 12-year long NATO-led International Security Assistance Force (ISAF) mission in Afghanistan, NATO created a Bi-Strategic Command Space Working Group in 2012. One of the more ambitious but key recommendations for improving NATO's space capabilities is the proposal for the creation of a NATO Space Operations Centre of Excellence to "offer recognised expertise and experience that is of benefit to the Alliance" (NATO, 2018). At the 2018 NATO Summit in Brussels, a decision was made to forge a joint NATO Space Policy – however, the timeline for the project is not yet established.

40. The emergence of new actors in space and the proliferation of national space programs are likely to increase the importance of these capabilities. While NATO members such as the United States, France, Germany and the United Kingdom are world leaders in the space field, and countries like Canada and Luxembourg play important if smaller roles, an increasing number of countries that were not traditionally players in the market are developing new capabilities. NATO thus confronts a competitive challenge in the space domain. Six countries launched satellites into the Earth's orbit for the first time in 2017. China has also rapidly increased its capabilities. Although a recent rocket failure has slowed China's progress, it is nonetheless on track to launch the first module of its space station by 2019 (Jones, 2018). Though its technology remains relatively unsophisticated, North Korea has also become a player in space, largely as a result of its military ambitions. It now appears interested in launching more satellites, and last launched an Earth observation satellite, *Kwangmyongsong-4*, in February 2016 (Panda, 2018). Iran's missile programme is also a major concern and has been the primary reason NATO has opted to construct a limited ballistic missile defence (BMD). As a range of countries enter this crowded market, NATO members will need to rely on their capacity to innovate to retain a competitive edge.

41. Private actors could pose potential challenges as well as opportunities. In March 2018, a Californian company was accused of launching satellites without government approval. Officials fear that these satellites "pose an unacceptable collision risk for other spacecraft" (Dvorsky, 2018). After a New Zealand company launched a large "disco ball" into space in January 2018, astronomers complained about the bright satellite's potential to interfere with their ability to observe and study space (Griffin, 2018). Ever lower entry barriers could also potentially engender problems of corporate negligence and misuse and might eventually open the space domain to malicious actors, including hackers and terrorist organisations. Western planners are already concerned about Chinese and Russian anti-satellite programmes and they now need to consider at least the possibility that these challenges could multiply as new actors launch orbital space endeavours.

42. Beyond security, however, space-based systems are an increasingly important part of national and international economic and governance systems in a variety of sectors ranging from telecommunications to environmental monitoring. While NATO serves mainly as a political and military organisation, its members' economic livelihood increasingly relies on unimpeded access to space and on its capacity to ensure the safety and survivability of space assets. The Alliance has an interest in preserving this economic capacity while deterring any threats that might make use of the space domain. At the technological level, military satellite designs increasingly incorporate elements of self defence capability to cope with potential threats to their survivability.

43. NATO Joint Air Power (JAP) remains highly dependent on member states' national space-based capabilities as they support Air, Maritime, Land, and Cyber domains. While NATO does not own or control space assets, JAP relies on them for "early and timely warning, space ISR, satellite

communication, - and the provision of Position, Navigation and Timing information." (NATO, 2018). Space assets have supported US military operations since First Gulf War (1990-1) – nicknamed "the first space war" and have supported critical NATO's military operations including the intervention in Yugoslavia in 1999, as well as, later, the wars in Iraq and Afghanistan (Tombarge, 2014).

V. OPPORTUNITIES

44. The growing capabilities of the commercial space industry offer several notable opportunities for Allied countries. These include economic benefits linked to spin offs, the possibility for interstate cooperation, and public-private partnerships.

A. ECONOMIC BENEFITS

45. The commercial space market is growing rapidly. Between 2001 and 2011, economic activity in space transportation and related industries increased by 239% (Whealan-George, 2013). In 2015, the global space market amounted to USD 323 billion, while it is projected to grow to USD 1.1 trillion by 2040 (Hampson, 2017; Sabbagh, 2017). While much of this activity is linked to well-established markets (e.g. satellites for the television industry — a business valued at USD 95 billion), space enables an increasingly wide array of economic activities. It is also displacing traditional systems. In the Flanders region of Belgium, for example, geo-fencing and satellite communication have replaced underground sensors in the tram network (Space Foundation, 2017). In the commune of Alban (Tarn, France), a satellite communication system is used to manage the city's drinking water and to provide real-time management and security of those supplies (Eurisy, 2018).

46. There are plenty of signs to suggest that the commercial space market will play an increasingly important role in the global economy. In its 2016 report, the US Federal Aviation Administration noted that the commercial launch industry had seen few changes in the last five years, but that the lack of observable change "belies what is taking place behind the scenes". The report further discusses how "[s]everal new launch vehicles are being developed specifically to address what some believe is latent demand among small satellite operators (Federal Aviation Administration, 2017)." The year 2016 was the most significant investment year for space-related start-ups, and investors committed USD 2.8 billion for space ventures. Small satellites, as this report has suggested, provide further opportunities. Various companies have announced plans to use these devices to provide worldwide, fast access to the internet (Scoles, 2018).

47. It is not possible to predict with certainty how these efforts will develop. Taken together, however, they point to the industry's growing interest in space. This is reflected in long-term investment trends. From 2012 to 2017 investment into space start-ups (USD 10,238.3 million) was nearly three time greater than the total investment in 2000-2012 (USD 3,688.7 million) (Bryce Space and Technology, 2018). This poses a range of regulatory and market structuring challenges that will lead to evolving partnerships between the industry and governments in order to ensure security, foster competition and encourage innovation.

B. INTERSTATE COOPERATION

48. An additional benefit comes in the form of potentially enhanced international connectivity. As discussed, the space industry has become increasingly internationalised. Companies like Thales Alenia Space, Airbus DS and OHB derive enormous benefits from workforces and supply chains that stretch across the European Union. These companies provide a model for similar multinational commercial ventures. They also show how commercial interests can redefine how the notion of national interest is understood. While companies within the United States are somewhat more restricted in their ability to cooperate with foreign firms as a result of ITAR (the US International Traffic in Arms Regulation) and other laws, many other countries do not face such rigorous

restrictions. That said, US firms have forged an array of important partnerships with their European counterparts.

49. Rising commercial interest in space has also triggered a renewed focus on the treaty regimes governing the extra-terrestrial commons. In the United States, Senator Ted Cruz has pushed for revisions to the Outer Space Treaty, which bars states from placing weapons of mass destruction in space and requires non-governmental entities to seek state approval prior to engaging in any space-based activity. He argues that the treaty, designed over half a century ago, is now outdated (Foust, 2017). There are worries that legal ambiguities are undermining the nascent commercial space sector, and that the lack of clarification of property rights could either stifle innovation or lead to conflicts over ownership of space rocks. In other words, the treaty is increasingly seen as outdated. Congress has recently considered the Space Frontier Act of 2018, which would extend the operation and utilisation of the International Space Station and streamline oversight of both launch and re-entry activities, and non-governmental Earth observation activities. The legislation appears to have a degree of bipartisan support in the US Senate with Senator Cruz hoping to pass it by the end of the year (Cruz, 2018).

50. Industry leaders are widely opposed to any revisions to the Outer Space treaty and have expressed reservations about "costly regulatory burdens" and the danger of uncertainty. This discussion is likely to grow more intense over the coming years. When the company Moon Express sought clearance to fly outside low Earth orbit in 2016, for example, it was unclear who within the United States Government had the authority to authorise that operation under the Outer Space Treaty. This issue points to the need to discuss treaty obligations and to undertake an effort to ensure that all participants in space agree to the same principles (Foust, 2017). Although a complete rewrite of the international treaty regime on outer space remains unlikely, there is clearly a need for an updated general code of conduct outlining the responsibility of states in overseeing commercial space activity planned and launched within their borders. The example of France, which amended its space legislation in 2008, is being studied by many countries, including the United States.

VI. CHALLENGES FOR THE FUTURE

51. Amid a field of opportunity, there are also substantial risks and challenges, including the potential cyberattacks, debris, regulatory barriers, and interstate hostility.

A. CYBER THREATS

52. Cyberattacks pose a growing threat to governments, companies, and civil society. While the linkages between this challenge and the space domain have not been widely explored, the potential hazard is no less significant. Attacks can come from individual hackers who want to test their skill, criminal organisations, terrorist groups or states seeking to achieve military advantage. Hostile operations might involve jamming and manipulating satellites to disrupt a communications network, targeting a satellite's control systems to shut it down or alter its orbit, or targeting ground facilities to inhibit their ability to receive or interpret space-related data (Livingstone and Lewis, 2016)[1]. Such attacks could have significant consequences and impact everything from telecommunications to credit card transactions. They could have immediate military implications if they were launched against military satellites, for example, employed for command, control and intelligence gathering purposes.

53. There are signs that some actors are already testing these capabilities. In 2011, the US-China Economic and Security Review Commission, a US government agency, accused China

[1] A basic overview of the technical components of these attacks can be found in the NATO Parliamentary Assembly's Defence and Security Committee's 2017 report, *The Space Domain and Allied Defence* [162 DSCFC 17 E rev.1].

of interfering with two US environment-monitoring satellites via a cyberattack on their ground station in Norway (Wee, Wills and Nishikawa, 2011). In September 2014, the US National Oceanographic and Atmospheric Administration had its weather satellite network temporarily taken offline by a serious hacking attempt. US officials again accused China, which denied the allegations (Flaherty, Samenow and Rein, 2014). While these incidents had few long-term national security consequences, they revealed vulnerabilities in space-based systems. These incidents point to the need for secure networks and control systems. In 2014, two Russian researchers identified at least 60,000 internet-connected systems that could be attacked through the internet (Pauli, 2014). In 2017, leaked documents suggested that Russian intelligence services were capable of hacking satellite signals using relatively simple techniques (Bing, 2017). Despite the obvious strategic benefits associated with NATO's increasing reliance on satellite support, that reliance also increases concerns about the vulnerabilities of those systems.

54. While military satellites are generally well-protected and designed with security in mind, commercial satellites tend to be significantly more vulnerable due to a lack of resources devoted to satellite security. Some commercial operations do not consider themselves vulnerable simply because they have not faced persistent threats of attack. Such complacency is dangerous in the current environment, and the private sector needs to dedicate more resources to defending space systems, even those with no military functions.

B. DEBRIS

55. As detailed in previous reports, space-based systems are also increasingly threatened by debris collisions. The number of satellites in orbit is rapidly increasing as states and commercial actors expand their capabilities. These new satellites are, in turn, orbiting in an environment increasingly crowded with defunct or damaged satellites. NASA and the CNES (*French Centre National d 'Etudes Spatiales*) currently trackthousands of orbital debris and there are millions more, ranging from paint flecks to shrapnel, which are far too small to track (Garcia, 2013). While these materials might seem benign, they travel at incredible velocities and can disable or even destroy large satellites in the event of collisions. The US Strategic Command recorded over 8,000 collision warnings in 2014 alone, 121 of which required emergency evasive manoeuvres (Pellegrino and Stang, 2016).

56. A significant source of concern is that space debris can create more space debris. When one object collides with another in space, both objects can fragment, scattering material that can cause further damage to other satellites and material. On 10 February 2009, a defunct Soviet-era satellite collided with an active American communications satellite, scattering a cloud of debris into higher and lower orbit (Broad, 2009). While not all collisions cause such dramatic structural damage, chips, craters, and erosion can gradually degrade a satellite's structural integrity. At best, these incidents damage multi-million-dollar spacecraft and endanger astronauts on spacewalks. At worst, a collision can lead to Kessler syndrome, a theoretical scenario wherein pieces of debris crash into each other, leading to bigger and more frequent collisions (Szondy, 2018). This worst-case scenario has the potential to fatally contaminate orbital ranges and render them inaccessible for generations.

57. Debris falling onto Earth also poses concerns over liability – whilst there have been no recent falls of debris with significant consequences, there is a concern over the fallout of such an event. For example, after China lost control of its Space Station *Tiangong-1*, it re-entered the atmosphere in April 2018, with most of it breaking apart and burning in the Earth's atmosphere. (Kuo, 2018). Some of the space laboratory's pieces survived the re-entry and crashed into the ocean. Had they crashed nearer to or on land, the issues of liability would have been much graver. The Space Liability Convention of 1972 states that "[a] launching state shall be absolutely liable to pay compensation for damage caused by its space object on the surface of the earth or to aircraft in flight" (UN, 1975). However, thus far, only one claim has been filed under this Convention when in 1978 the Soviet satellite Kosmos 954 crashed on Canadian territory.

58. There have been attempts to reduce the amount of space debris through regulation and sustainable practices. By establishing requirements to reduce debris, Europe has reduced the level of space debris produced by its programs (Pellegrino and Stang, 2016). The Inter-Agency Space Debris Coordination Committee, an international government forum for space debris activities, and the United Nations Committee on the Peaceful Uses of Outer Space have similarly sought to establish internationally accepted protocols and guidelines for preventing substantial releases of space debris. Government and private actors have also explored technological solutions, such as capturing and removing satellites. However, as stated by the European Institute for Security Studies, these technological solutions would require "an internationally agreed legal regime […] since the owner of the debris is the sole party responsible for it" (Pellegrino and Stang, 2016).

C. TREATY AND REGULATORY ENVIRONMENT

59. Efforts are underway to update national and international space law. Space law experts at the International Law Association have noted that the Outer Space Treaty's general framework still has "gaps […] which remain open to interpretation." These gaps include a lack of clarity regarding the ownership of certain celestial bodies and the legal status of resources there. There also legal challenges linked to controlling the hazards posed by space debris in the Earth's orbit while rules are needed to govern private sector activity in space. (Currie, 2008) While the 1979 Moon Treaty provides some guidance, including rules on the extraction and management of celestial natural resources, these provisions require substantial international cooperation to ensure enforcement. This treaty obliges states to share extracted resources equitably with other states. To date no spacefaring state has ratified it.

60. This legal void has allowed some governments to pass national laws to regulate space activity, but these laws do not necessarily conform to international obligations and laws in other states. The United States and Luxembourg allow their citizens and companies to possess, own, transport, use, and sell resources extracted from a celestial body. These laws grant ownership after the resources have been extracted to try to avoid conflict with the Outer Space Treaty's prohibition on corporate ownership of celestial bodies. The head of the European Space Agency's legal services, Marco Ferrazzani, has expressed an interest in developing new rules pertaining to space mining (Doldirina, 2018). While space mining on any mass scale still appears to be far off, these examples demonstrate the potential for conflict. The absence of a clear international consensus on appropriate conduct in space may lead to contradictory regulations from different national governments. These contradictions, in turn, could either stifle commercial activity or discourage enforcement of these different obligations.

61. A related issue is the existence of Cold War-era national regulatory regimes that inhibit commercial activity. The most frequently discussed example of this situation is the United States International Traffic in Arms Regulations (ITAR), which restricts and controls defence and military-related technologies. The goal of the law is to impede other countries from reproducing US military capabilities, but academics and commercial space advocates have suggested that these regulations can also have unintended consequences that inhibit legitimate commercial developments. Many US companies working on space projects are prohibited from hiring or working with foreign persons without an export license or from sharing minor parts and components. As a result, commercial space companies outside the United States have simply sought to reduce their dependency on US materials (De Selding, 2016).

62. Some organisations, such as the Space Foundation, have urged these regulations to be revised with input from experts in the space industry. Other recommendations have focused on the creation of defence trade treaties to enhance collaboration among companies in Allied states. In this respect, the work of the UN Committee on the Peaceful Uses of Outer Space (COPUOS), especially its Legal Subcommittee, set up in 1959 by the General Assembly, is crucial in directing the development of international law on space exploration."

63. Most of what passes for governance takes the form of non-legally binding norms as well as UN resolutions and government regulations and practices. Because space law is so limited, national laws assume a degree of importance, particularly the laws of major actors in space. Interestingly there are no binding international laws on debris and debris generation. But an *ad hoc* group has been formed to draft technical regulations to limit debris. It has no legal standing as such, but many countries have adopted these standards as well as other non-binding agreements. This kind of practice helps impose a degree of uniformity to national rules governing activities in space. It also points to the degree to which rule making for operations in space has become a bottom-up rather than a top-down process. It is also worth noting that article 189 of the EU's Lisbon treaty creates a shared competence on some space related matters. The European Space Agency has also helped furnish EU members with a set of shared norms even if these norms, are not elevated to the level of law.

D. INTERSTATE COMPETITION AND THE MILITARISATION OF SPACE

64. The thrust of international laws governing space is to ensure that access to outer space and celestial bodies remains unimpeded. The 1967 Outer Space Treaty, for example, reaffirms the importance of peaceful and lawful exploitation of the domain (UN General Assembly, 1966). Several international agreements reflect the international community's resolve to create an overarching code of conduct for those operating in space. In addition to the aforementioned 1979 Moon Agreement, and the 1972 Space Liability Convention, the Rescue Agreement of 1968 and the Launch Registration Convention of 1975 have sought to regulate the modalities of space exploration. More recent discussions highlight the difficulties of reaching an international agreement on these matters. From 1985 to 1994, an *ad hoc* committee on a Prevention of an Arms Race in Outer Space (PAROS) treaty discussed and negotiated the creation of such an agreement. Whilst China and Russia did propose a Treaty on the Prevention of the Placement of Weapons in Outer Space and of the Threat and Use of Force Against Outer Space Objects (PPWT), the United States continues to oppose the initiative, arguing it is "fundamentally flawed" and lacks important provisions. (Foust, 2014) The discussion of PAROS continues in the UN Conference on Disarmament, and a number of countries remain very focused on matters pertaining to access to space. In its 1999 National Security Strategy, the United States declared that "unimpeded access to and use of space is a vital national interest — essential for protecting U.S. national security" (White House, 1999). The United Kingdom's National Space Policy emphasises the country's reliance on access to space services for a wide array of essential services (Javid and Letwin, 2015).

65. Recent events suggest that space may no longer remain a peaceful common and that there is a real possibility that access might be limited under certain conditions. Speaking before the US House Armed Services Committee's Subcommittee on Strategic Forces, Department of Defense officials stated that the United States "can no longer view space as a sanctuary" because "potential adversaries understand [US] reliance on space and want to take it away" (Marshall, 2015). Dan Coats, the US director of National Intelligence, echoed these remarks in his May 2017 testimony to the Senate Select Committee on Intelligence. He stated that China and Russia felt increasingly compelled to undermine US military advantage as it related to military, civil, and commercial space systems and that both countries "are increasingly considering attacks against satellite systems as part of their future warfare doctrine" (Coats, 2017). In 2015, China unveiled its Strategic Support Force to develop and coordinate its space, cyber, and electronic warfare capabilities (Office of the Secretary of Defense, 2017).

66. The United States' mounting concerns about space-related risks are reflected in President Donald Trump's recent call for the creation of a Space Force and the allocation of USD 8 billion to space security systems over the next five years. In August 2018, the US Department of Defence outlined a plan to create such a force charged with defending US interests with aggressive offensive capabilities (Bachman, 2018). The proposed Space Force would likely assume

responsibilities for the US Air Force's role in tracking the world's active satellites to make sure they do not collide with one another.

67. To date, states have resisted positioning destructive weapons in space. However, various terrestrial weapons systems do depend upon space-based infrastructure and are produced by the private sector. Concepts for intercontinental ballistic missiles are designed and manufactured by private companies following competitive bidding processes in the United States (Erwin, 2018). Both the United Kingdom and France have recently made important investments in long-range missile systems that expand the core capabilities of the Alliance (Baldwin, 2017). SpaceX, meanwhile, has secured classified contracts with defence and security agencies (Seemangal, 2017). Russia and China have developed increasingly sophisticated precision-guided missiles and military communications technology. Both countries have also developed counterspace systems, sought to modernise their military satellites, and developed anti-satellite missiles.

68. While there has not yet been an attack on a commercial spacecraft, these developments could have a potentially chilling effect on the private sector's willingness to invest in the domain. Corporations do not like uncertainty and instability. They are unlikely to respond positively if they see their multimillion-dollar spacecraft threatened as part of a space arms race. It makes eminent sense, therefore, to continue diplomatic efforts to promote the non-weaponisation of space and to discourage threats against spacecraft.

69. Finally, the overarching Space Policy which NATO agreed to create at the Brussels Summit affirms the commitment of Allies to promote the non-militarisation of space (NATO, 2018). Experts are not short of suggestions for the creation of bodies within NATO which would deal explicitly and exclusively with space security issues. Clearly it will not be easy to strike a balance between securing satellites as essential infrastructure for daily activities on Earth and working to avoid or even to trigger a military space race. NATO is well prepared to share expertise and foster consensus-building on these matters in ways that will reinforce security in the broadest sense of the term.

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